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DIESEL ENGINE GENERATORS AND POWER SYSTEM PROTECTION

Vineet Kumar*1

*1Department Of Computer Engineering, Sachdeva Institute Of Technology, Mathura, India.

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ABSTRACT

Power systems form the essential backbone of the modern systems with energy generation resources allowing a smoothen demand optimization. Generation lies in the heart of the power system, each type of generation has its own unique characteristics, advantages, and challenges. Diesel generators are distributed generation for majority of the power systems at customer end. Even with integration of renewables from solar and wind there are baseload power supply added. Vehicle-to-Grid connectivity arises solving power system protection problems. Interrupting capacities of the circuit breakers intelligently from the controls configured as per the breaker operating modes increased the need of using power electronics for improved grid controls. From generation to transmission and distribution these systems require stepped planning for operation and continuous innovation in smart grid technologies.

Keywords: Power, Generation, Diesel Generator, Controls, Power Systems.

I. INTRODUCTION

Electricity, the power blood of any process industry, is very essential for the running of any plant. Being a continuous process industry, needs continuous supply of electrical energy to run its operation in the plant [1] [2]. The engine is a turbo-charged inter-cooled 4-stroke diesel engine with direct fuel injection. The engine block is cast in one piece. Modern applications of engines were substituted for electric motors (PMSM and BLDCM) [3] [4]. But the major mechanical constituent like bearings are similar. The main bearings are of hanging type. The charge air receiver is cast into the engine block as well as the cooling water header. The crankcase covers are made of light metal, & sealed against the engine block by means of rubber sealing. The lubricating oil sump is welded. The cylinder liners are designed with high collars & drilled cooling holes [5]. The cooling effect is optimized to give the correct temperature of the inner surface. The liner is provided with an anti-polishing ring in the upper part of the bore to eliminate the risk of bore polishing. The main bearing are fully interchangeable tri-metal or bimetal bearings' which can be removed by lowering the main bearing cap. The crankshaft is forged in one piece & is balanced by counter weights as required. The connecting rods are drop forged. The big end is split & the matting faces are serrated. The pistons are fitted with a skirt lubricating system [6] [7]. The piston ring set consists of three chrome plated compression rings & one chrome plated spring-loaded oil scraper rings. Hour hydraulically tensioned screws fix the cylinder head made of special cast iron. The head is of the double deck design & cooling water is forced from the periphery towards the center giving efficient cooling in important areas. The inlet valves are stilted & the stems are chromium plated. The exhaust valve also with stilted seats & chromium plated stems, seal against the directly cooled valve seat rings. The seat rings made of a corrosion & pitting resistant material are changeable. The camshafts are made up from one-cylinder pieces with integrated cams. The injection pumps have integrated roller followers and can normally be changed without any adjustment. The turbochargers are normally located at the free end of the engine. On a V-engine there are two chargers, one for each bank. The charge air coolers are made as removable inserts on the V-engines two identical ones. Electrical components for a synchronous generator are driven by the engine for backup operations [8]. Limitations of engine generators from emissions motivate researchers for alternate energy and technology in [9] [10]. Distributed energy generation from advanced power engineering FPV solutions [11] is specific to GHG emission reduction targets by many countries. The specifications of an engine generator are mentioned below:

Specifications of Engine [12] [13]

- SPEED :750 rpm
- COOLING :Water-cooled
- NO. OF CYLINDERS :18

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- CONFIGURATION :Vee
- BORE :320 mm
- STROKE :350 mm
- COOLING SYSTEM :LT/HT Water
- FUEL :LDO/HDO Multi-fuel
- LUBE OIL REQUIREMENT :2670 L (Sump)
  :300 L (Pipes)
- SP. FUEL CONSUMPTION :10 g/kWh (HFO)
- LUBE OIL CONSUMPTION :1.2 g/kWh
- FUEL CONSUMPTION :1.2 KL/hr.
- OUTPUT AT ALTERNATOR SHAFT :5822 kW
- MEAN PISTON SPEED :8.75m/s
- MEAN EFFECTIVE PRESSURE :21.3 bar
- PISTON DISPLACEMENT PER CYLINDER :28.15 l
- NO. OF VALVES PER CYLINDER :2 inlet valves, 2 outlet valves
- DIRECTION OF ROTATION FACING FLYWHEEL :Clockwise
- ENGINE NOMINAL OUTPUT :7380 kW_m

II. BIASED DIFFERENTIAL PROTECTION

Maloperation of Differential Relay Due to OLTC Tap Change During External Fault Condition as shown in Figure 1. Figure 2 is bias curve.

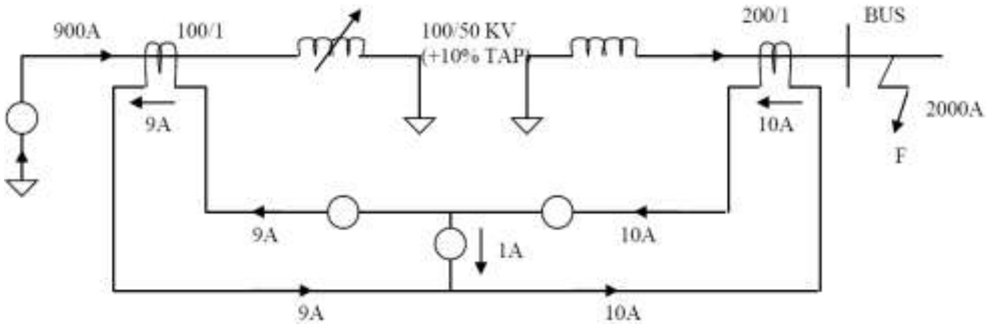

Figure 1: Protection System [14]

Introduce a tap of +10%. The voltage ratio of Transformer – becomes 110KV/50KV. For a External fault of 2000A, CT Primary current on LV side is 2000A and CT secondary current is 10A. CT primary current is reflected on HV side is 900A and CT secondary current is 9A. Hence there exists a flow of differential current (1A) , which flows in differential relay and it operates.

Bias to Prevent Maloperation on through Faults

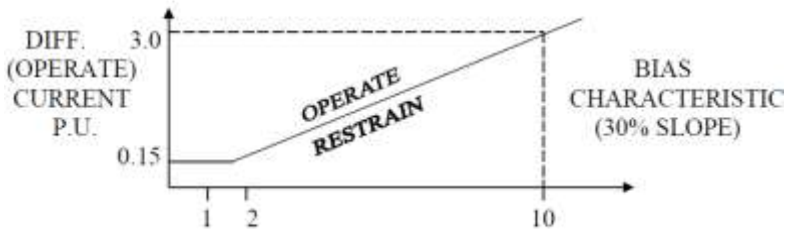

Figure 2: Protection Curve [14]

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Modified pickup of relay due to restraint effect of Bias windings: -

$I_{OP} = 30\% \times \frac{(10+9)}{2} + 0.15$ (MOD) = 2.85 + 0.15 = 3.0A

Bias through current is $\frac{10+9}{2} = 9.5$

For this current, for relay setting of 0.15A, relay operates for a Differential current of 1A. Introducing a bias of 30%, Relay setting becomes 3A. Hence for a differential current of 1A relay remains in the restrain region. Thus introducing a bias will increase the relay pickup setting. The undesired relay operation are from unbalances from Tap-changing in the power transformer, CT currents and relay tap ratings experience mismatching, and CT's on either side of the power transformer have error differences

Protection of Shunt Capacitor Bank

A Capacitor bank is defined as "the group of individual unit capacitors which are connected in series – parallel combination so as to give the required KVAr output at the specified voltage and current." A unit capacitor is a simple encapsulated capacitor which has several 'capacitive elements' connected in series parallel combination to obtain a specified output.

Unit size is from 25 – 100 KVAr

Voltage rating vary from 440V to 11KV. 50 c/s

Capacitor banks, as any other electrical equipment, must be provided with suitable protection and in most cases each capacitor unit will be provided with a primary protection fuse. Overcurrent protection to cover bus faults between the capacitor bank and its controlling circuit breaker, Over Voltage Protection, Unbalance Protection, and Under Voltage Protection are essential capacitor protection. Individual unit is provided with protection fuse. When partial short circuit of the individual unit appeared this fuse operate and prevent damage to the adjacent healthy units The individual fuse also provide an indication of the faulty unit and the same can be replaced without any difficulty.

Overcurrent Protection

To guard against the faults on capacitor leads between the circuit breakers and the units, it is normal to provide overcurrent and earth fault protection using I.D.M.T.L induction disc relays. When the source is earthed, two overcurrent and one earth fault relays are used so as to cover both phase and earth faults. When capacitors connected with sources of harmonics such as generators, transformers and arc furnaces etc they may increase the current beyond permissible limit of 130%. I.D.M.T.L relays used for overcurrent protection when set to operate at 130% of full load current give adequate overload protection to capacitors. Large rating critical banks are provided with separate thermal overload relays matched with the thermal characteristic of the capacitor. To limit the inrush current during switching and overcurrent due to harmonics sometimes series reactors having 6% of capacitance reactance are connected on the phase side of the capacitors.

Over Voltage Protection:

The causes of Overvoltage are Normal system voltage fluctuation and Voltage Rise when capacitors used under light load conditions. To protect capacitor bank from overvoltage normally an overvoltage relay with setting of 110% or higher is provided. A slight time delay is necessary to override the transients OR an overvoltage relay with inverse time characteristic can be used. This relay is energised from a P.T. connected to the main busbar on the source side of the circuit breaker controlling capacitor bank.

Unbalance Protection:

In an ungrounded star connected bank, a voltage operated relay is connected across the open delta of VTs across the capacitor banks. For a Star-Star capacitor bank with floating neutral connection, a current relay operated off a C.T. in the floating neutral connection is used. Relays used should be provided with a time delay device to prevent operation under transients and to allow individual fuses to isolate the faulty units. For arrangement, it is usual to provide a C.T. of ratio 10-5/1A and overcurrent relay with setting of (10-40)% of 1A followed by time delay relay. The following points have to be carefully analysed in the application of relays for neutral unbalance protection: The minimum setting available on the relay should not be more than the

voltage/current available to the relay when one or more units fail causing 110% over voltage across the remaining units. And, the thermal rating should be adequate in the unlikely event of one phase of the bank shorted to earth. Sometimes for large banks a two stage protection is provided, first stage for giving an alarm on loss of one capacitor unit and second stage for tripping the breaker when overvoltage on healthy units exceeds 110%.

Unbalance detection in Delta Connected banks:

The VTs are connected across any one of the series groups of each phase. The secondaries of the VTs are connected in open delta to feed the voltage relay. Under healthy conditions, the distribution of voltages across each series group of the 3 phases is identical in magnitude but 1200 displaced in phase. Consequently open delta output is zero. However, when unit failure occurs in any one of the series groups of any phase, the voltage distribution of the affected phase is distributed, thereby producing an open delta output to operate the relay.

Under Voltage Protection:

This Protection is provided to disconnect the bank under low voltage conditions and also to provide interlock in the closing circuit. Relay provided for this application should have a high resetting ratio and is connected to the bus VTs.

Abnormal Conditions:

Transformer	-	Overload - Loading Pattern
		Downstream short circuit faults
		Over fluxing
Motor	-	Overload – Mechanical Loading
		Unbalance supply voltage – single phasing
		Locked Rotor
		Prolonged Start
		Under voltage
Generator	-	Overload – Uncleared downstream faults
		Field Failure
		Under voltage
		Under frequency operation
		Pole slipping
Faults		-In feed – Strength of source %X
		Mechanical Stress – Damage outage

Silent Sentinels:

Current -	Increase Load current – Fault current	
		Mechanical Stress – Damage
Voltage -	Rated – Low voltage zero	
Frequency	-	Rated – Low value
Phase Angle	-	Near Unity power factor to 0.2 or 0.15 lag

Protective Relaying

Electrical equipment failures are inadvertent from errors resulting in intolerable outages. Provisions to mitigate the equipment failures from power systems faults of the protective devices, there must be additional provisions. These provisions are: Design optimization to reduce failures, and Mitigation of the failures. Modern power system design employs varying degrees of both resources, as dictated by the economics of any particular situation. Some of the features of design and operation aimed at preventing electrical failure are: Provision of adequate insulation, Design for mechanical strength to reduce exposure, and Proper operation and maintenance practices. The basic and principal function of protective relaying system are associated by presence of mitigation effects of short circuits, other abnormal operating conditions – to give trip command to circuit

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breaker, minimizing damage to equipment and interruptions to service when electrical failures occur. A secondary function of protective relaying - To provide indication of the location and type of failure. – Faster repair – means for analyzing the effectiveness of the fault-prevention Fusing is employed where protective relays and circuit breakers are not economically justifiable.

Primary Relaying – First line of defense

Backup Relaying acts only when primary relaying fails [15]. Must operates with sufficient time delay. Primary relaying failures are basically from: Current or voltage supply to the relays, D-C tripping-voltage supply, Protective relays, Tripping circuit or breaker mechanism, and Circuit breaker. It is highly desirable that back-up relaying be arranged so that anything that might cause primary relaying to fail will not also cause failure of backup relaying. Failure of protection system to perform its function correctly is often due to incorrect application of instrument transformers. Hence, current and voltage transformers are regarded as part of protection system and carefully match with relays to fulfil essential requirement of the system.

Functional Characteristics of Protective Relay

- Sensitivity: Any relaying equipment must be sufficiently sensitive so that it will operate reliably, when required.
- Selectivity: It must be able to select between those conditions for which prompt operating is required and those for which no operation, or time-delay operation, is required.
- Speed: It must operate at the required speed.
- Reliability: That protective-relaying equipment must be reliable is a basic requirement. Reliability can be tested by actual field test. It should be assuming to trip proper breaker for a given fault and refrain other relaying equipment from tripping.

III. EVALUATION OF PROTECTIVE RELAYING

Protective relaying minimizes: Cost of repairing the damage, likelihood that the trouble may spread and involve other equipment, the time that the equipment is out of service, and the loss in revenue and the strained public relations while the equipment is out of service.

Specific Application in Plant Distribution System

MAIN TRANSFORMERS - STAR/STAR CONFIGURATION

HV side earth fault relay should be directional earth fault relay instead of IDMT plus Instantaneous earth fault relay. Unit protection schemes needs to be commissioned systematically by selecting proper ICTs and detailed testing by carrying our through fault stability test and internal fault sensitivity test.

NEUTRAL EARTHING SYSTEMS

NGR earthed for EB supply and DG supply. Single phase to earth fault current values are limited to rated current of main transformer for EB supply, 100A or less for DG supply. This sensing of earth fault current for incomers, bus coupler and higher size outgoing feeders produced by DG sets during isolated running is not possible with conventional IDMT earth fault relays.

6.6 KV MOTORS – LRS START

Thermal unit, curve selection to be verified correctly. I1 and I1(t) settings are not correctly designed for LRS starting conditions. Auxiliary transformers provided with CDAG 51 or CDG 61 relays correctly. But adopted settings to IDMT and INST. Units needs to be reviewed. Switchboard incomer figures are provided with IDMT over current plus instantaneous relay. Instantaneous unit gives non-discriminate tripping for downstream faults.

PCC INCOMING AND OUTGOING FEEDERS

Thermal magnetic relays settings to be put correctly to match with loading condition and fault levels.

IV. CONCLUSION

The critical aspect of the power systems is to ensure there is subsequent reliability, safety, and stability of the system after clearing faults from short circuit, overcurrent, and transient conditions. This paper achieved through coordinated arrangement of the protective devices inclusive of the practical case of transformers and motor protection. The diesel generators addition to the system required implementation of both remote and

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local backup protection schemes. Selective isolation of the faults causes operators in isolation of the faults to readily clear. Power flow during fault conditions switches the buses in main-tie-main of breaker and half scheme system securing the unnecessary activations. Additional distributed energy resources from proposed protection accommodate the vehicle-to-grid or grid-to-vehicle distributed generation. Tailpipe emissions from engine generators have motivated clean energy initiatives by many researchers.

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